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DEVELOPMENTAL VERSION OF THE ROOFDRY MODEL: FINAL REPORT

PART IX REPORT
RAPPORT PARTIE IX

Canada Mortgage and Housing Corporation
Société canadienne d'hypothèques et de logement

Canadian Housing Information Centre
Centre canadien de documentation sur l'habitation

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July 18, 1989

Mr. Don Fugler
Research Division
Canada Mortgage and Housing Corporation
National Office
682 Montreal Road
Ottawa, Ontario
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Re: Developmental Version of the ROOFDRY Model: Final Report

Dear Don:

We have completed our investigation of the feasibility of developing the ROOFDRY model based on WALLDRY algorithms. We have chosen this letter format for final reporting in the interest of brevity and budget efficiency. The following summarizes the progress made as a result of this contract:

- The first milestone report was sent to you March 31, 1989 which described the adaptation plan for converting the WALLDRY algorithm into the ROOFDRY model - see Attachment "A" for reference. Since that report the following progress has been made:

- The "SUN" algorithm for predicting incident solar gain on any surface in any orientation and incline was adapted from the Gorman model and used in this model to generate solar data. We used the original WALLDRY files as they exist to produce the cloud cover data needed to run this "SUN" algorithm. To test the "SUN" algorithm against the original WALLDRY data, we compared a month of predicted solar radiation for vertical surfaces in the south, east, north, and west faces using both the WALLDRY algorithm and the "SUN" algorithm. The results of these comparisons are shown in Figures 1 and 2 for the south and north directions. Figure 1 shows the results for the first week of 1974 in Toronto, for the south direction. For clear days both algorithms yield very similar results; however, on cloudy days, the WALLDRY solar incidences are predicted to be somewhat higher than the "SUN" solar incidences. This pattern was also evident in the east and west directions (not shown).

Figure 2 shows the comparison for the north direction for the first week of 1974 in Toronto. Here the differences show up more consistently, although the order of magnitude of the solar incidences are very much smaller than on the south face. Apparently, the diffuse components of solar radiation are handled differently by WALLDRY and Gorman's "SUN" model. One possible explanation for the discrepancy is that the cloud cover data on the current WALLDRY meteorological data disks is a result of a "blend" of cloud cover index and cloud opacity. It is possible that the "SUN" algorithm requires only the cloud cover index and not the opacity. The use of a pure cloud cover index with the "SUN" program would almost certainly make the solar incidences predicted by "SUN" more in line with the WALLDRY incidences. At this stage we are not in a position to judge which algorithm is more reliable; nevertheless, the "SUN" algorithm is more general than the WALLDRY one and suits the purpose of the ROOFDRY program. We have therefore decided to implement the "SUN" solar algorithm in the ROOFDRY program and this has been incorporated successfully.

Figure 3 shows the resulting implementation of the ROOFDRY program using the "SUN" algorithm and the "blended" AES cloud cover data. It shows the resulting solar incidence profiles at noon hour for the south direction, for a roof with a one to three pitch.

Note: It was noted in the comparison between the original WALLDRY solar data and the new "SUN" algorithm that the original WALLDRY data did not begin at hour one of January 1, 1974. There appears to be some lag offset in the first hour and this is different for each weather data set of the WALLDRY data. As a consequence, some adjustment has to be made to line up the weather data with the actual hour of the first day of January. One of the results of this is that at noon hour data printed out by the program is not actually noon hour data as it stands now. As a result maximum solar incidences printed out by WALLDRY and ROOFDRY at noon will appear to be lower than the actual noon reading because of the offset in time (i.e. it may be a 10 a.m. or a 2 p.m. reading). This has very little effect on the seasonal drying characteristics. It nevertheless should be corrected for both WALLDRY and ROOFDRY application.

Further modifications include:

- All of the input screens were redesigned by Ken Ruest with some guidance from myself. The ROOFDRY model can now be implemented with its own dedicated input screens. A number of help screens remain to be drafted and a number of modifications might be required for ease of operation; however, the screens provided with the ROOFDRY program that is sent under the same cover will allow you to implement the program with some ease.

- The thermal air flow and moisture flow algorithms were adapted from the WALLDRY program to ROOFDRY, according to what was described in the March progress report.

No major glitches were involved in the conversion. A number of modifications to the overall program and outputs were brought about in this adaptation.

- The graphics output screens were adapted to show ROOFDRY results. (See for example Figures 4A and 4B.)

A few example runs were made using the new ROOFDRY model for cathedral ceiling with a ridge and a pitch of one to three in the St. John's area. The results of this work are reported in Figures 4, 4A, 4B, 5, and 6.

Figure 4 shows the drying profile of the sheathing for the south facing slope, the "ridge" part, between the south and the north slopes, and the north slope of a cathedral ceiling in St. John's. (The roof slope was 1 to 3.)

One of the noteworthy characteristics of this result is the delayed drying of the centre core of the sheathing until about May, after which fairly steady drying occurs on all faces. As well, the north face sheathing appears to dry faster than the south face. This apparent anomaly is explained as follows. Because the roof is symmetrical and the north and south ends are joined, a symmetrical flow system with air coming through the leaks in the roof and flowing out the ridge vent is expected; however, this symmetrical pattern is unstable. As a result, a leakage flow is set up that is greater on the south side. When room air enters the roof space, it heats up the air space temperature, and through buoyant action, perpetuates that mode of flow. Solar action also encourages greater south-side buoyancy. Thus, room air leakage occurs on the south side more often than on the north, and therefore, greater wetting of the sheathing occurs on the south side during the winter months. The south and ridge portions of the roof experience more wetting than the north side. Accordingly the north side sheathing dries faster. Perfect symmetry in actual roof distribution of leaks would of course not exist. What this simulation is showing is that the effect of systematic leakage from inside the house to the roof space has more bearing on the drying rate than whether the slope of the cathedral ceiling is on the north face or on the south face.

Figure 4A shows what the surface layers of the sheathing were doing at the same time as the inner layers shown in Figure 4. Here rapid wetting of the sheathing surfaces was seen throughout the roof, again with the south and ridge portion of the roof experiencing more wetting than the north side. Wind patterns and wind pressure coefficients will affect these wetting and drying patterns. Figure 4B shows the effect of a "sheltered" condition for which the wind does not systematically draw air through the roof. The wind pressure coefficients applied to the model should be the subject of further study.

Figure 5 shows the drying pattern of the cross members that are in the cathedral ceiling air space. Fairly slow but systematic drying is predicted for the cross members.

Figure 6 shows the drying pattern of the joists embedded in the insulation. The joists are predicted to experience rapid drying action due to the steady temperature gradient through the insulation that surrounds the joists.

Conclusions

It appears that the ROOFDRY model can be developed based on the WALLDRY models on a rather economical basis, by using most of the algorithms and approach of the WALLDRY model. The existing preliminary model is evidence that a realistic adaptation can be set up and that initial findings can be determined from the model.

One of the key initial findings is that significant air leakage from the house to the air space can dominate the drying patterns of the roof regardless of roof orientation. The effect of differential solar gains between north and south slope on a relatively shallow cathedral ceiling appear to affect the drying patterns in only a minor fashion. This contrasts to Gorman's attic model results which showed faster drying on the south slope than on the north. The difference in the two model results can be explained by the fact that attics generally have steeper pitches than cathedral ceilings. As well, attics experience more general mixing because of their open space, whereas cathedral ceilings, because of their constrained space, can experience systematic flow patterns through the rather narrow air space.

Because of this promising first step, we would recommend further work in the development of the ROOFDRY model that would see the inclusion of field-developed air tightness coefficients for the roof sheathing and the ceiling. Further application of the model would result in refinement of existing algorithms, elimination of bugs that have not yet been found, and improving the inputs screens for more "friendly" access. Future work should also include a thorough review of the materials properties database.

We call your attention to the appendix which includes a copy of the progress report, and to the attached diskettes supplied which have all the original program codes in QUICKBASIC 4 and the execution files.

Yours truly,

SCANADA CONSULTANTS LIMITED

Michael C. Swinton, P. Eng.

MCS/clm
Enclosures

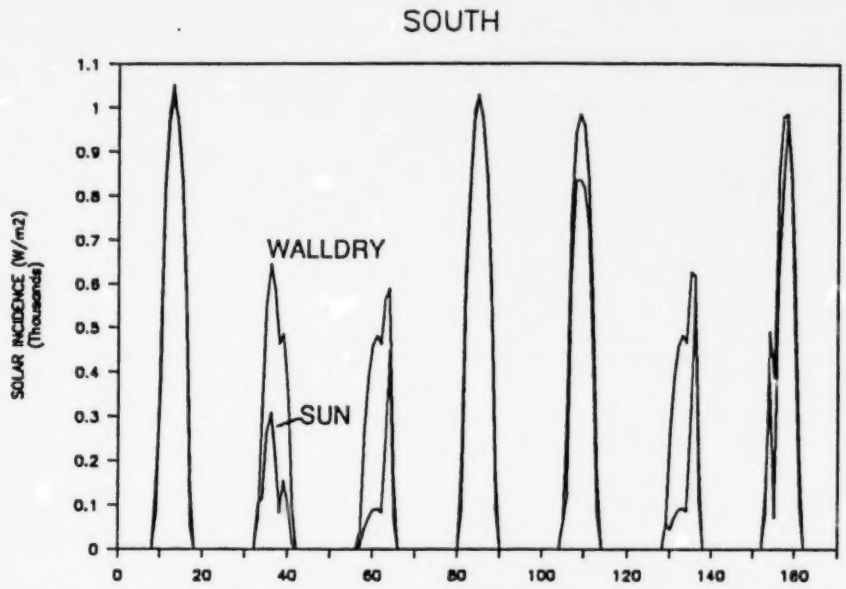

FIGURE 1. COMPARISON OF WALLDRY & "SUN" GENERATED SOLAR DATA TORONTO, FIRST WEEK IN JANUARY.

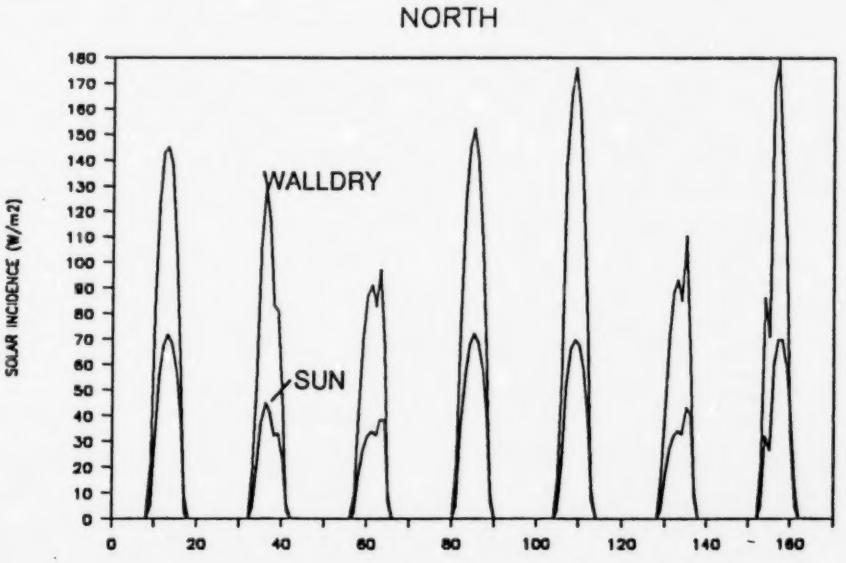

FIGURE 2. COMPARISON OF WALLDRY & "SUN" GENERATED SOLAR DATA TORONTO, FIRST WEEK IN JANUARY.

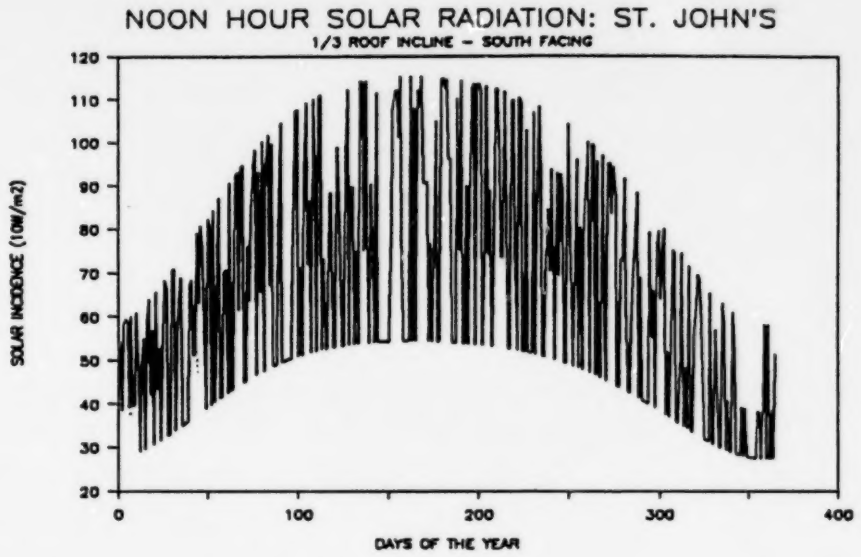

FIGURE 3. SOLAR INCIDENCE ON A SLOPED ROOF PREDICTED BY THE "SUN" ALGORITHM

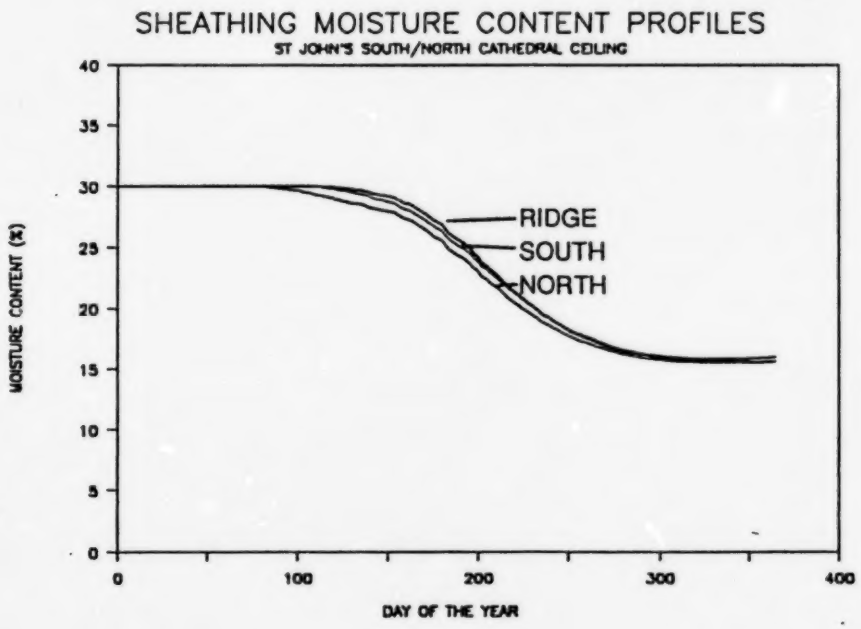

FIGURE 4. SAMPLE RESULT OF THE ROOFDRY PROGRAM: SHEATHING DRYING

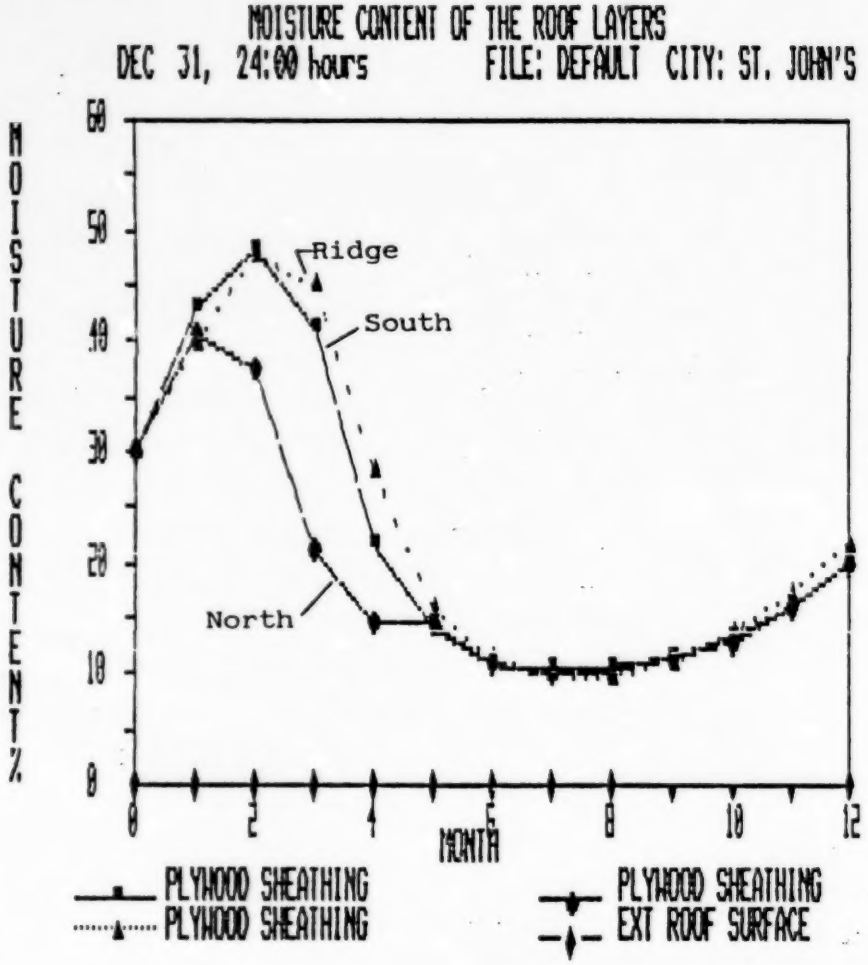

FIGURE 4A

Sample Output of the ROOFDRY Program: Sheathing Surface Layers

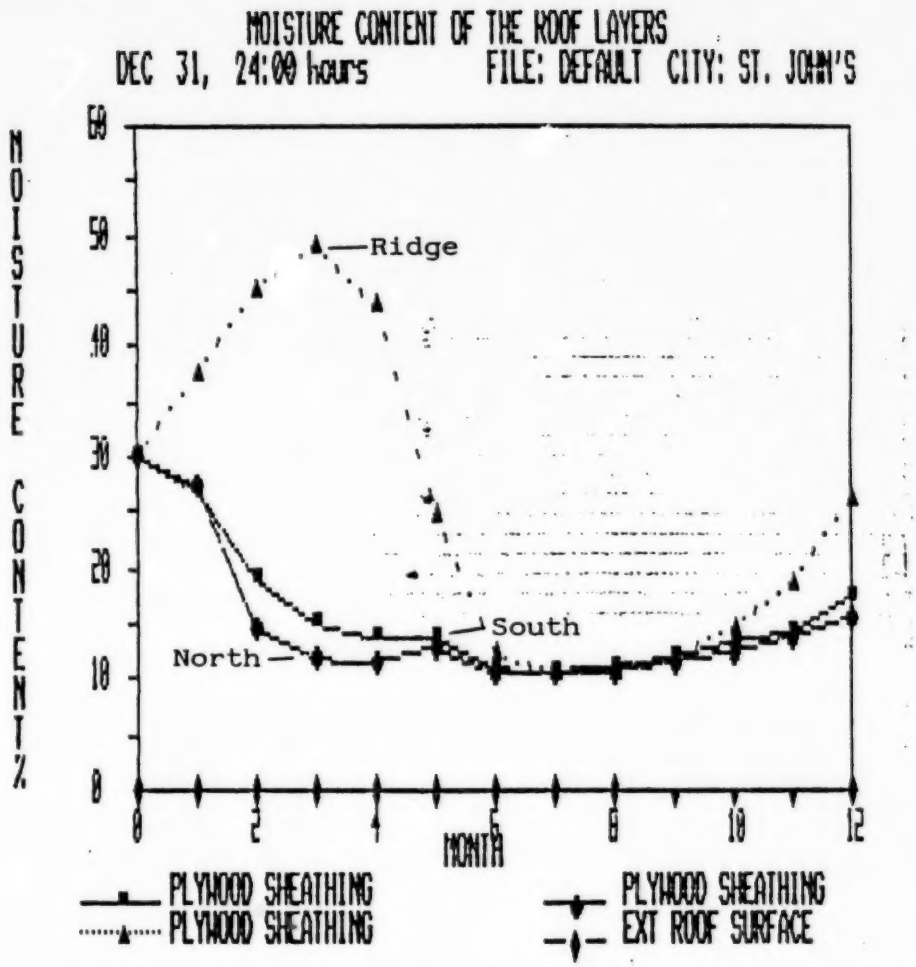

FIGURE 4B

Sheathing Surface Layer Drying Pattern with a Sheltered Roof

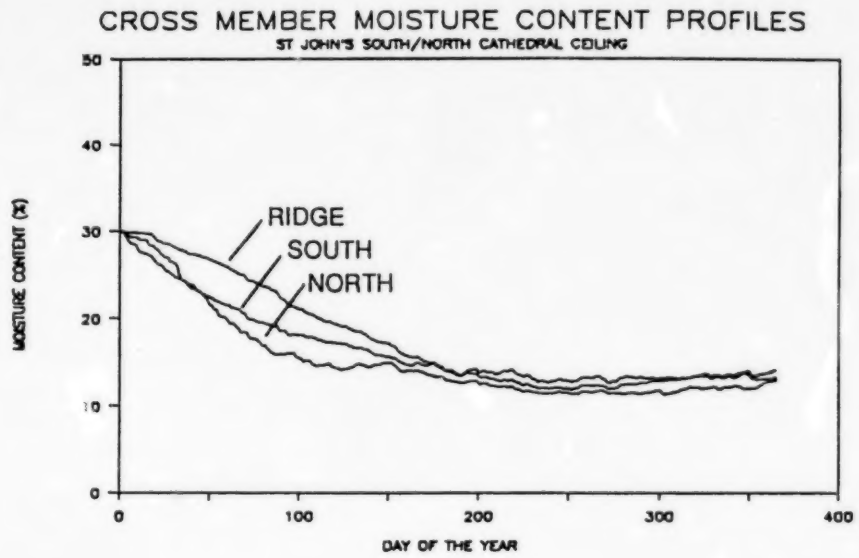

FIGURE 5. SAMPLE OUTPUT OF THE ROOFDRY PROGRAM: CROSS MEMBER DRYING

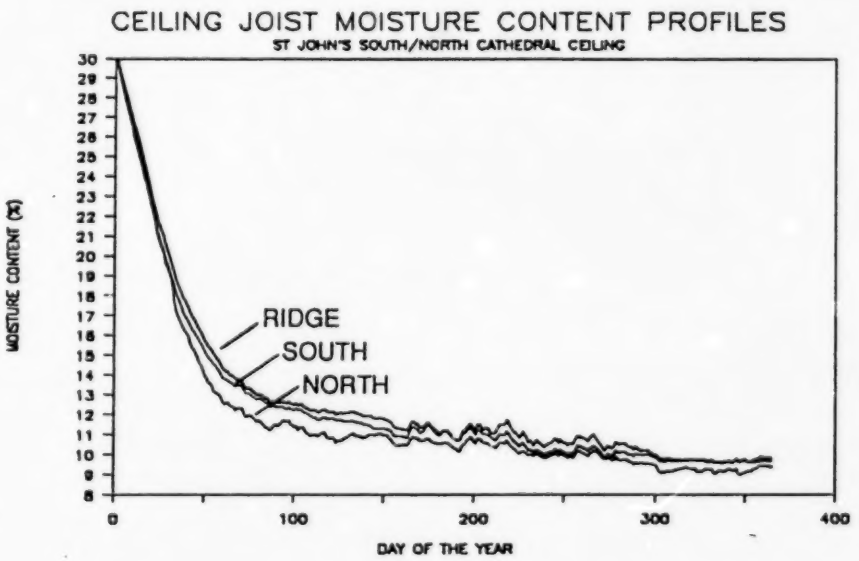

FIGURE 6. SAMPLE OUTPUT OF THE ROOFDRY PROGRAM: JOIST DRYING

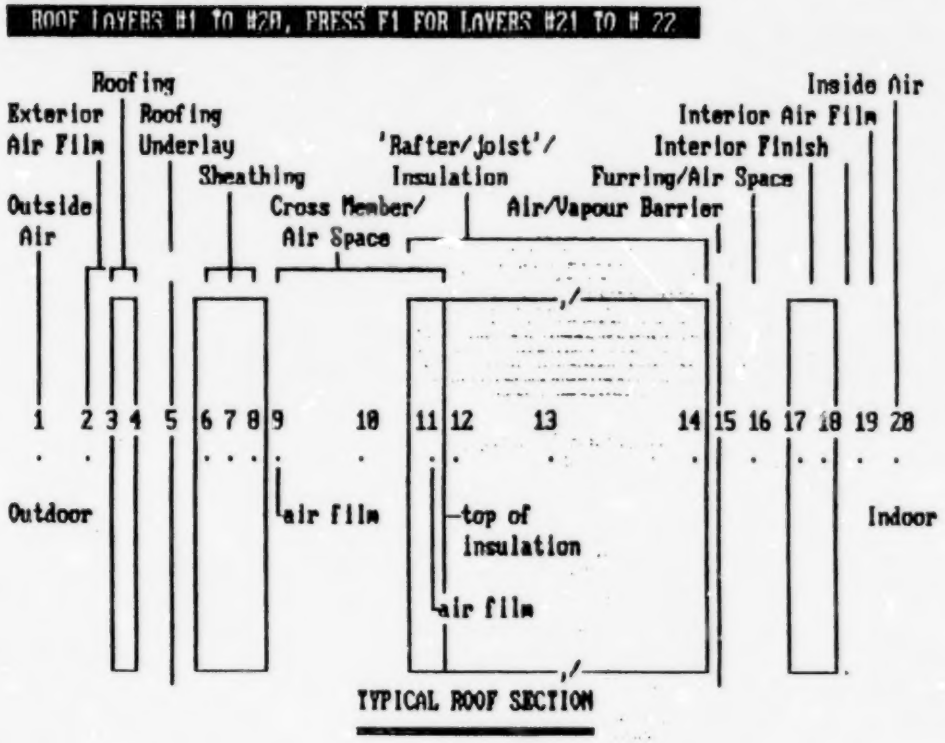

FIGURE 7

SCHEMATIC DIAGRAM AND CALCULATION NODES: THE "ROOFDRY" MODEL

ATTACHMENT "A"

ADAPTATION OF THE WALLDRY PROGRAM TO STUDY THE FLOW OF AIR AND MOISTURE IN CATHEDRAL CEILINGS AND ATTICS

PROGRESS REPORT: RESEARCH DESIGN

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prepared for

Canada Mortgage and Housing Corporation

by

Scanada Consultants Limited

March 31, 1989

OBJECTIVE

The objective of this project is to investigate the feasibility of developing a detailed hour-by-hour simulation model of the moisture flow in cathedral ceilings, based on the algorithms and modelling approach used in the WALLDRY program. This adaptation of WALLDRY will be based in part on insights gained from the GORMAN model of attic moisture flows to assist in model specification and validation. The new model will account for the materials and assembly techniques used to build cathedral ceilings, and will allow for the specification of assembly and opening air leakage characteristics for which test procedures are currently being developed.

This objective will be met by developing and delivering to CMHC a draft computer-based simulation model of moisture flow in cathedral ceilings - "ROOFDRY". A report will be produced outlining the changes made to the WALLDRY program to develop the draft ROOFDRY model. The most promising avenues of further modelling and testing will be identified, as well as major impediments to full model development.

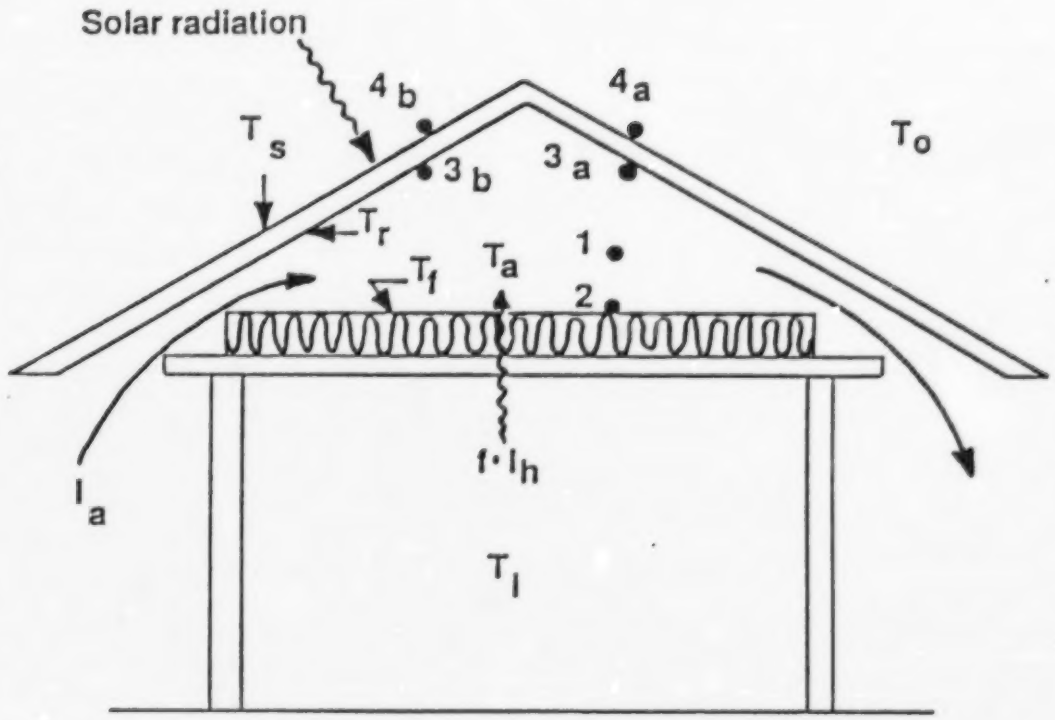
REVIEW OF THE GORMAN MODEL

The Attic Humidity Model developed by Thomas Gorman (ref. 1) is a computerized hour-by-hour simulation model of the relative humidity of the attic air space and of the moisture content of the sheathing facing that air space. The model is driven by hourly weather data that includes outdoor temperature and RH, solar and cloud cover data, and snow accumulation. This model and its report will be a useful reference to this project in several ways:

- because the science of attic humidity prediction involves the same phenomena as the prediction of moisture flow and accumulation in cathedral ceilings, Gorman's approaches to modelling the various phenomena - and his use of other referenced techniques developed by others - can serve to confirm current approaches used in WALLDRY and can help guide improvements and fill gaps in known approaches, where these exist. Similarities and differences in modelling approach are as follows:

    - Gorman uses a "nodal" approach to moisture, energy, and air transfer - a technique used in WALLDRY. The schematic diagram for his entire attic model (reproduced here from page 61 of ref. 1) is very similar to what the WALLDRY diagram looks like for one slice through the wall (e.g. for one siding lap) (Figure 1), the main difference being that Gorman requires two sets of nodes for the two pitches, involving different solar incidences on either side of the ridge.

    - Gorman used the Cleary approach (ref. 2) for modelling moisture transfer between air and wood surfaces - an approach that is consistent with WALLDRY. On the other hand, he has expanded on the technique for predicting moisture transfer within the wood materials. This approach is of interest since, for development of the WALLDRY model, we assumed that



•	Nodes for heat balance
T_a, T_I, T_f, T_o, T_r, T_s	Temperatures of attic, indoor air, attic floor outside air, underside of roof, surface of roof
f	Fraction of air entering attic
I_a, I_h	Ventilation rates for attic and house, vol. changes/hour

Schematic of the Gorman Attic Model (Reproduced from Figure 1)

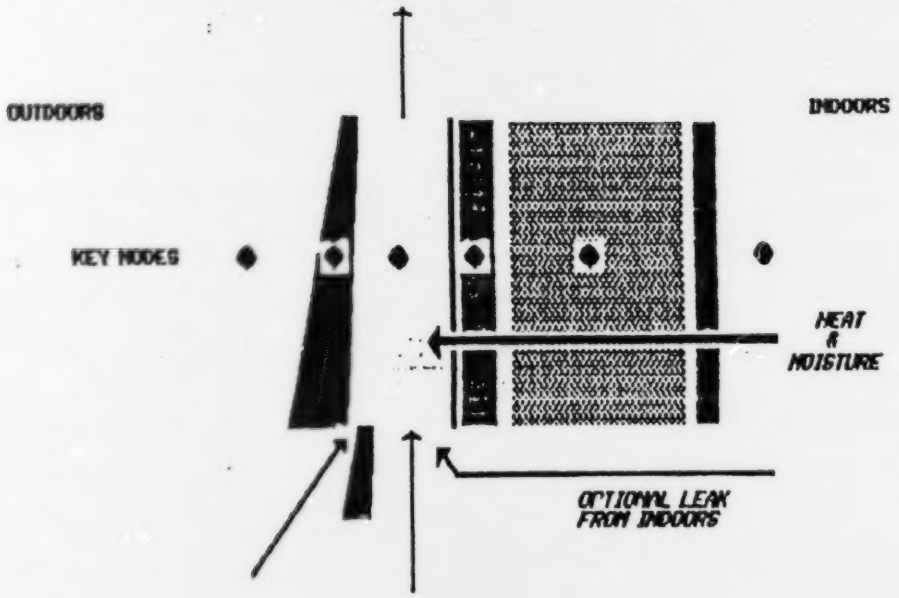


FIGURE 1. SIMPLIFIED SCHEMATIC OF THE WALLDRY MODEL
(ONE OF NINE ELEMENTS VERTICALLY)

similar forces acting at the material surface were also acting within the material - an assumption that appears to have stood up to preliminary validation, but is certainly subject to a second opinion.

- Gorman's roof solar algorithms are of interest as these are not programmed in WALLDRY. His validation of the roof solar algorithm includes comparisons of predicted and measured roof shingle temperatures which appear to be quite successful.

- The computer model provided has been validated, and thus is an easily accessible reference for validating modules within ROOFDRY.

The Gorman model has been implemented at Scanada. Typical outputs are presented in Figures 2 and 3. (These graphs are labelled as we understand them currently - original graph labels were missing). It may be possible to perform a ROOFDRY simulation using the weather data provided with Gorman's program, to produce similar performance characteristics. This comparison might highlight similarities and differences in the attic and cathedral ceiling systems models. The Gorman weather dataset is similar to the WALLDRY dataset, and includes "snow accumulation", and a generalized algorithm for producing directionally specific solar data from standard weather data, both of which are needed and not currently in the WALLDRY weather files.

In summary, the Gorman work appears to be a valuable additional reference for the modelling task at hand.

Note: in our opinion, and apparently in Gorman's, the program is decidedly unfriendly, and thus offers no useful guidance on program presentation!

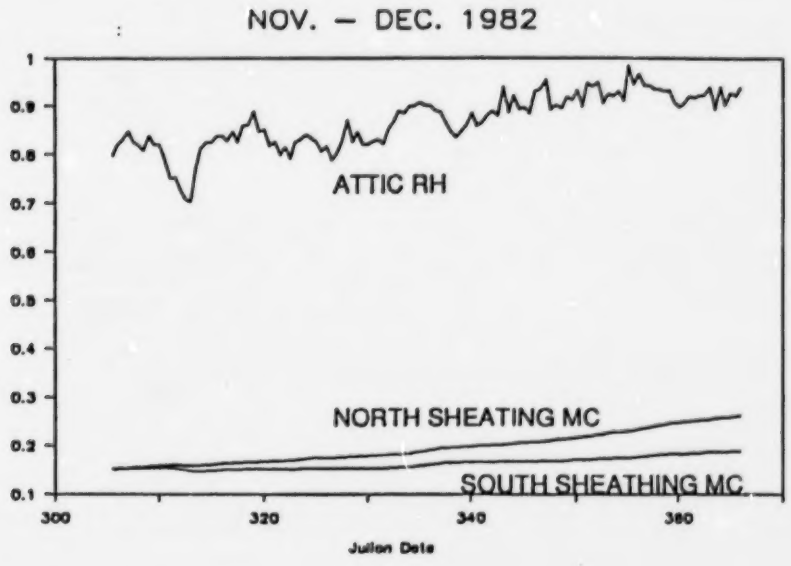


FIGURE 2. TYPICAL OUTPUT OF THE GORMAN ATTIC MODEL (NOV-DEC)

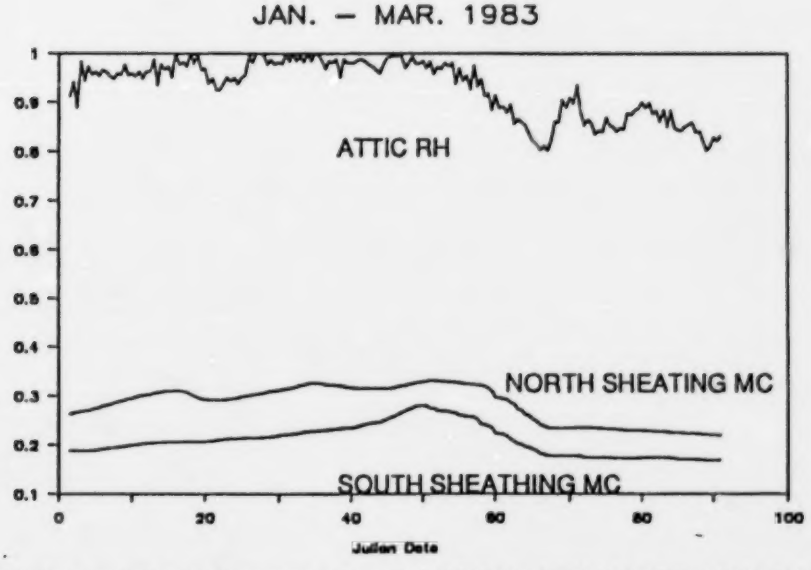


FIGURE 3. TYPICAL OUTPUT OF THE GORMAN ATTIC MODEL (JAN-MAR)

IDENTIFICATION OF THE DIFFERENCES BETWEEN A WALL AND A CATHEDRAL CEILING FROM THE MODELLING PERSPECTIVE

Differences in Wall and Cathedral Ceiling Construction

Figure 4 shows a typical cross-sectional diagrams of a cathedral ceiling, for reference purposes. This figure is comparable to Figure 1.

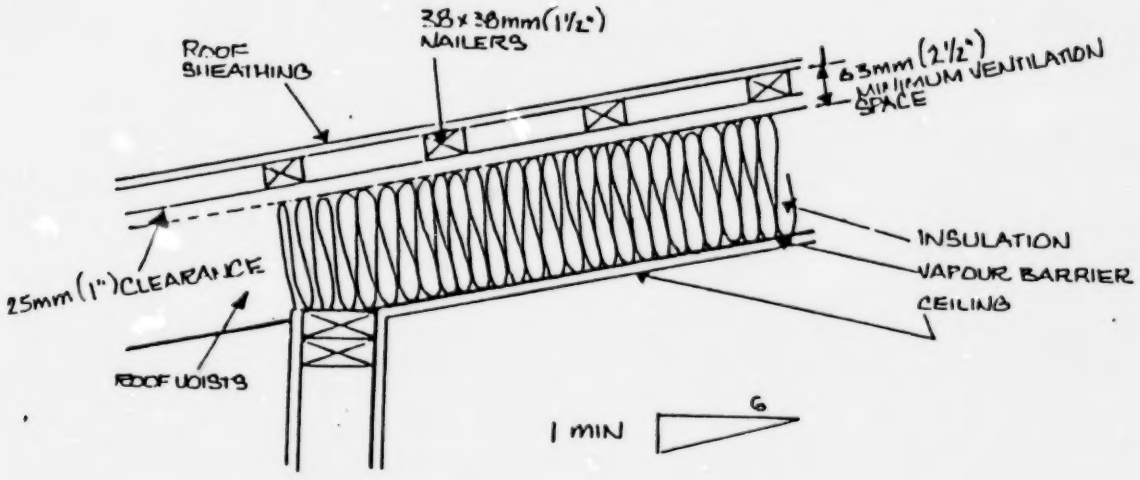
Differences in the Systems Model

Although the differences between wall and roof construction are obvious in appearance and orientation, we are not so much concerned here about the differences per se but how those differences affect the modelling of weather, energy flows, air flows, moisture flows, and the overall system interactions.

The actual differences between a wall and roof when viewed from the perspective of the systems model are actually few in number. Walls and roofs differ fundamentally in only three respects:

- The planned air space for the flow of outside air within the structure is **behind the sheathing** in cathedral ceilings rather than behind the siding for strapped walls. If the cathedral ceiling were perfectly sealed, then the current WALLDRY system model structure could be used directly to simulate that type of roof, without modification to the system model (modifications to the materials properties and solar data would of course have to be addressed, but these are input modifications). The moving air space layer in the systems model is the link between the moisture, air flow, and energy modules - all modules come together in this layer of the program. Shifting the position of this layer within the structure can be handled in the current program by judicious changing of air space layer identification within the program. No algorithm changes are needed. The current leakage sites that model air exchange through siding leaks would be used to represent air flow through planned leaks in the roof and distributed leaks between the air space in the roof and the house interior. The roof angle and height above the Vertical Centre of Leakage of the house have to be added into the buoyancy equations already in the model.

- Snow and ice cover on the roof in winter represent an outer layer on the roof that is variable in thickness and in thermal and moisture transfer properties. This "roof layer", strictly speaking, has no analogous layer in the wall, but in fact it does: the current air film in the wall model has variable thermal properties depending on winds. This film can be turned into a "general interface" layer whose combined properties now account for several environmental factors, including snow and ice. If handled in this way, the systems model is unaffected. Algorithms will have to be developed to establish the total effective thermal resistance of the snow/ice cover. The change in emissivity of the layer will have to be accounted for. The existence of snow or ice indicates that the saturated vapour pressure of water is acting at the snow/roof interface. This interface would form the new boundary to the moisture flow model when there is snow on the roof.



Cross Sectional Diagram of Typical Cathedral Ceiling Construction
(Reproduced from Guide and Illustrations for Part 9 of the Ontario Builder's Code)

Figure 4

- A considerable proportion of the wood mass in the cathedral ceiling is exposed to the air space, as opposed to the insulation; e.g. the cross members and the portion of the joists or truss members sticking out of the insulation. This quantity of wood will have to be identified by the user (with guidance from the program), and its moisture balance will have to be accounted for in separate nodes. Also, does the protruding portion of the joist or truss act as a "fin" which emits moisture into the air space, and accordingly, does a wet stud dry more through this fin than out of its sides, through the insulation? The current WALLDRY modelling technique is based on the assumption that all stud drying is initially in the lateral direction and out through the insulation rather than directly out through the wood member. This assumption will be kept for the ROOFDRY model but should be reviewed at the validation and refinement stage.

All other differences, though numerous, appear to represent only minor changes or adjustments to existing sub-models in the WALLDRY model structure, or changes and additions to the inputs and outputs. These minor adjustments are listed below.

Additional Materials Used in Roofs

The material properties database will have to include roofing material properties such as those for built up roofs and roof shingles.

The Weather Data Files and Solar Algorithm

The weather data file will have to include solar radiation for the appropriate sloped surface. The appropriate algorithms to generate this data have been provided by Gorman in the form of the "SUN" program, listed in Appendix C of ref. 1.

This program needs Azimuth of the location to be specified, as well as horizontal solar intensity and hourly cloud cover data which are available from the dataset produced by RWDI.

Alternately, Gren Yuill, in his current review of WALLDRY, may provide CMHC with an appropriate solar module that may be usable for ROOFDRY.

The Air Flow Module

The algorithms to the air flow module will be unchanged. The proposed distribution of the ten available leakage sites in the program are shown in Figure 5.

Wind pressure coefficients will have to be produced for the leakage and planned openings to the outside. Airtightness characteristics will be specified by the user for each leak location and planned opening.

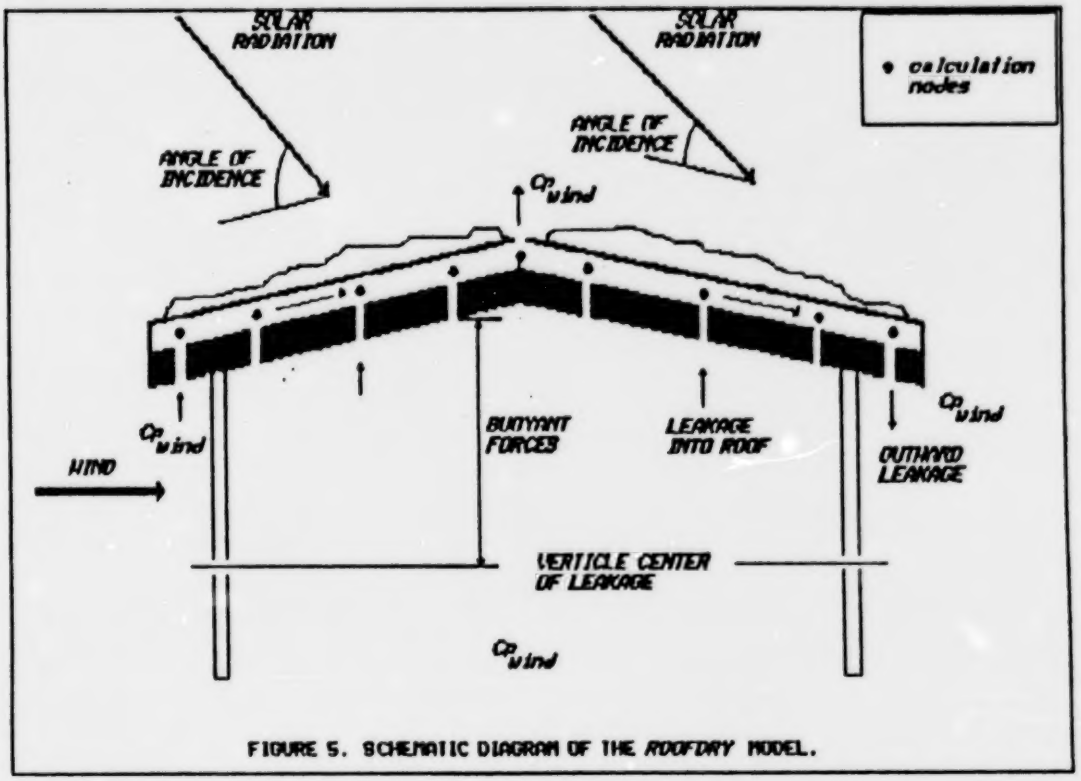


FIGURE 5. SCHEMATIC DIAGRAM OF THE *ROOFDAY* MODEL.

The Moisture Flow Module

When the roof is clear of snow, the exterior air and its RH and temperature will define the boundary conditions to the moisture model as in the WALLDRY program. When snow or ice is present, the new boundary to the moisture model will be the snow/roof interface. The boundary condition will be independent of outdoor RH, as the interface will have the saturated vapour pressure at the appropriate temperature.

As with the WALLDRY model, air entering the air space in the roof will be at the outdoor RH and temperature.

Account will have to be made of the additional storage capability of the cross members, and that portion of the joists not covered by insulation. The portion of the joist covered by the insulation is already accounted for in the present program.

The Energy Flow Module

The actual module itself will not change; however, the solar inputs (boundary conditions) and variable R-value of the snow effects will have to be resolved.

The energy flow module will also incorporate the air change heat transfer in the nine elements of the air space, and the latent heat effects of moisture evaporation from surfaces.

Input/Output Modules

In spite of the widespread usability of the WALLDRY algorithms in the ROOFDRY model, a number of key input screens will have to be redesigned or relabelled to indicate typical roof components rather than wall components.

Less work will be required to adapt the output screens which are generic in nature.

RECOMMENDATIONS

The development of a draft ROOFDRY model based on WALLDRY algorithms appears to be achievable. The available model structures of both WALLDRY and of Gorman's "SUN" model make it possible to produce at least one simulation within the context of this contract, thereby demonstrating the feasibility; however, the draft model will not be developed to the refined state of its "parent", the WALLDRY program, due to the large number of small adjustments that have to be implemented and verified for programming integrity. Close consultation with the project officer will have to be undertaken to establish what can be reasonably left out of this initial conversion process, while meeting the intent of the contract.

REFERENCES

1. ***Modelling Attic Humidity as a Function of Weather, Building Construction, and Ventilation Rates***, by Thomas M. Gorman, Ph.D. thesis at the College of Environmental Science and Forestry, State University of New York, December 1987.